An Experimental Study of Performance and Presence in Heterogeneous Haptic Collaboration: Some Preliminary Findings

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Abstract

Based on a distributed architecture for real-time collection and broadcast of haptic information to multiple participants, heterogeneous haptic devices (the PHANToM and the CyberGrasp) were used in an experiment to test the performance accuracy and sense of presence of participants engaged in a task involving mutual touch. In the experiment, the hands of CyberGrasp users were modeled for the computer to which the PHANToM was connected. PHANToM users were requested to touch the virtual hands of CyberGrasp users to transmit randomly ordered letters of the alphabet using a pre-set coding system. Performance accuracy achieved by a small sample of participants was less than optimal in the strict sense: accurate detection of intended location and frequency of touch combined ranged from .27 to .42. However, participants accurately detected the intended location of touch in 92% of the cases. Accuracy may be positively related to pairwise sense of co-presence and negatively related to mean force, force variability, and task completion time.

1. Introduction

In many applications of haptics it will be necessary for users to interact with each other as well as with other objects. We have been working to develop an architecture for haptic collaboration among distributed users. Our focus is on collaboration over a non-dedicated channel (such as an Internet connection) where users experience stochastic, unbounded communication delays [1-5].

In our most recent work, we have focused on improving our system by implementing the synchronization mechanism as a collaboration library. To achieve the desired visual and haptic capabilities for the collaboration program, a model of a human hand was developed for the computer to which the PHANToM was connected. Each segment of the hand is a 3D model. Each component of the hand (the palm, the three segments of each finger, and the two segments of the thumb) was imported separately into the haptic environment. The components were arranged and aligned visually to produce the image of the hand. In the code, the components were organized in a tree-like architecture. To maintain the shape of the hand as it moves during simulation, the movements of components more distal to the wrist are described in the reference frames of adjacent components more proximal to the wrist. For example, the tip of a finger moves with respect to the middle segment of the finger, the middle segment moves with respect to the first segment of the finger, and the first segment moves with respect to the palm. This utilization of relative motion reduces the amount of information required to describe the motion of the hand. Only the rotation angles of each component (relative to its 'parent' component) are needed. The x-y-z coordinates of each component relative to its parent are fixed, and therefore need not be updated. (The only rectangular coordinates that update are for the wrist.) The CyberGrasp computer sends updated transform parameters, which the PHANToM computer uses to generate new coordinate values for the hand.

The other major issue concerning development of the hand model involved contact sensing by the PHANToM. In the haptic environment, regular, solid geometric shapes provide the PHANToM with substantial contact force. This was not so with the hand. Its two-dimensional triangular components would tend to let the PHANToM pass through, with little tactile indication of contact. This problem was solved in a makeshift fashion. A skeleton was constructed out of solid geometric shapes, and placed inside the hand model, to provide contact sensation for the PHANToM. In this solution, PHANToM users see the VRML hand, and feel the skeleton. (We will address this pass-through issue in future work by considering alternative surface representations.)

2. Experiment

2.1 Experiment Design

Here we report an experiment to evaluate our collaborative system. Some preliminary data were collected from a small-scale study of heterogeneous haptic collaboration, in which one participant, wearing the CyberGrasp, interacts over the Internet with another participant at a remote location (another lab area), who is assigned to a computer with the PHANToM haptic stylus attached. The participants are assigned to an experimental task that assesses the ability of a subject wearing the CyberGrasp to recognize and discriminate among patterns of passive touch with respect to frequency and location, and the ability of the PHANToM user to communicate information effectively through active touch.

We can call the participants, respectively, P1 and P2. Participant P1's monitor shows a model of P2's (the CyberGrasp wearer's) hand, which is updated in real time to reflect the current location and orientation of P2's hand and fingers. P1's task is to use a PHANToM haptic stylus, the tip of which is represented by an enlarged round ball, to communicate information to P2 through a tactile "Morse code" which maps the number of times a particular digit is "touched" onto the 26 letters of the alphabet. A keypad showing this mapping is visible on P1's display. P2 holds her hand stationary during this process. P2 then enters (or has entered for her) the letters she thinks she has received into a keypad visible on her own display, from which they are logged into a word file. On P2's monitor, only the keypad is visible; P2 is unable to see the hand display. The two subjects can communicate with each other via a text-based messaging system, sending pre-programmed messages such as "Experiment begins," "New word," "New letter," "Ready for next letter," "Next trial," and so on. All text messaging between the partners is logged and time-stamped.

2.2 Participants

Participants were recruited through notices placed on bulletin boards and circulated through the campus BBS and student mailing lists. For participants to be eligible they had to be right-handed, over 18, and unacquainted with any other person planning to volunteer for the study. Upon acceptance into the participant pool, volunteers were randomly assigned to the "CyberGrasp" condition or the "PHANToM" condition and directed to one of two lab locations on campus. The target N of pairs for the study is 25; we are currently collecting data and report here on a very small sample of three pairs.

2.3 Procedure

Upon arrival at their respective lab locations, participants were then provided with a PowerPoint tutorial tailored to the type of haptic device to which they were assigned. The tutorial introduced them to haptics and in the case of the PHANToM user provided an opportunity for them to practice using the device for active exploration of a digital object. The CyberGrasp user's role in the experiment was to be a passive recipient of touch and as such did not "practice" but was simply taken through the calibration process upon completion of the tutorial.

The experimenters in their respective lab locations communicated with Motorola Talkabout radios to coordinate opening of the collaborative workspace. Participants joined in the workspace over an ordinary Internet connection. Next, they were provided with oral instructions which reinforced the explanations of the experimental task provided in the tutorials. As an added check to ensure that any obtained errors in location or frequency of touch were attributable only to the haptic interaction and not to participants' misreading of the code, participants were required to state aloud which finger they intended to touch and how many times they intended to touch it. When the oral instructions were completed, the investigator supervising the PHANToM user started a process for recording the haptic data stream (capturing and time-stamping applied force at 10ms intervals) [6] and signaled through the keypad that the experiment was to begin. The investigator supervising the CyberGrasp user minimized the collaborative workspace window so that the participant would respond only to the haptically communicated information. The pair of participants worked their way through a word list that contained all 26 letters of the alphabet, sorted randomly into nine sets of three- and two-letter words. At the conclusion of the trials, participants completed a post-task evaluation with items adapted from the Basdogan et al. measure of co-presence. [7] Among the questions of interest: Did the subject feel present in the haptic environment? Did the subject feel co-present with the remote partner? Did the subject believe that the remote partner was a real person? Subjects were also asked to make attributions about their partners with respect to standard dimensions of perception (unsocial-social; sensitive-insensitive; impersonal-personal; cold-warm) (Sallnas, Rassmus-Grohn, & Sjostrom, 2001). [8] (Findings with respect to the person perception data will be reported elsewhere.)

3. Results

3.1 Accuracy

Performance for all three pairs was seemingly poor. Accuracy of the best pair was 42.3%. The next best pair got 38.4% of the letters correct, and the least effective pair only 26.9%. However, examination of the confusions data indicates that, with the exception of the thumb (see Table 1, below), most of the confusions resulted from an overestimate of the number of times the finger was tapped. Only 8% of the errors made were egregious, e.g., the recipient was confused about which finger was being tapped. We present two of the confusions matrices below, the matrix for the ring finger (Table 1) and for the thumb (Table 2).

Table 1. Table of Confusion for the ring finger *

	Reported Number of Taps						
		1	2	3	4	5	6
Number of Taps Called for by Code	1		x		x		
	2			x			
	3				xx x		
	4			xx			
	5						
	6						

*Confusions as to number of taps are represented by small x's.

Table 2. Table of Confusion for the thumb*

	Reported Number of Taps								
		1	2	3	4	5	6	Finger	
								Mid.	Pinky
Number of Taps Called for by Code	1		x						**X**
	2	x							
	3	x					x		
	4		x					**X**	
	5	xx					x		
	6					xx			

*Confusions as to number of taps are represented by small x's. Confusion as to location of touch are represented in bold capital X's at the right-hand side of the table

3.2 Performance and presence variables

Performance values for the participant pairs for (a) the number of points at which there was measurable force, (b) minimum force, (c) maximum force, (d) force variability (standard deviation of sampled values), (e) time to task completion, and (f) accuracy (percentage of correctly decoded letters) are presented in Table 3 (a)(b). Co-presence data is also reported in Table 3 (b). Comparison of the most accurate pair (Pair 3) and least accurate pair (Pair 1) indicates that the less accurate pair had far fewer sampled points with measurable force, greater mean force, higher force variability, and longer time to task completion (although taken over all pairs these relationships are not monotonic with respect to task completion time). Comparison of the most and least accurate pairs (Pair 3, Pair 1) indicated that perceived co-presence was rated higher by the more accurate subjects, and by both members of the pair. However, taken over all pairs the relationship between co-presence and accuracy is not monotonic for the PHANToM users.

Table 3. Performance variables and co-presence ratings for participant pairs

(a)

Pair	N Points Measurable Force	Min Force	Max Force	Mean Force	Force S.D.
1	0494	.0005	.8530	.2788	.2623
2	6607	.0005	.8974	.2278	.2501
3	3688	.0005	.9039	.1240	.1699

(b)

Pair	N Points Measurable Force	Min Force	Max Force	Mean Force	Force S.D.
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4. Discussion

Although the accuracy levels obtained in this small sample appeared to be low, it was in fact the case that in 92% of the instances the passive touch recipient (the CyberGrasp wearer) was able to distinguish which digit was being touched. The bulk of the obtained errors resulted from an overestimate by one of the number of times the digit was tapped. There are a number of possible explanations, two of which seem most likely. First, there may have been incidental vibration of the CyberGrasp unrelated to the intended activity of the PHANToM user. If that were the case, however, there would have been more reports by the

CyberGrasp user that his or her partner was “trying to touch several fingers” at once. Our experience to date indicates that touch on some of the middle digits can produce vibration in neighboring digits. What we did observe is that the PHANToM user, having only a single point of contact, often “missed” connecting with the partner’s fingers on the first several tries at a new letter, and would frequently follow up on a light application of force to the finger with a stronger one, even though the deformation of the finger model on the first occasion of contact was clearly visible on the monitor. Further practice and more intensive coaching in the tutorial on interpreting the visual indicators of contact should improve results in future experiments. Incorporation of immediate feedback about performance accuracy on initial trials should also improve performance on subsequent trials.

Poorest performance was obtained for information communicated through taps to the thumb. In addition to the two cases in which the CyberGrasp wearer perceived a tap intended for the thumb to be directed to another digit, the thumb confusions matrix shows clearly that the passive recipient consistently underestimated the number of taps relative to the number intended by the active partner. The most plausible explanation has to do with the comparative difficulty given the orientation of the hand of contacting the palmar face of the thumb with the PHANToM. Many of the taps were applied to the dorsal side.

Although we expected that greater mean force would be associated with greater accuracy; that does not appear to have been the case in this small sample. There may be a force threshold which once met is adequate for detection, or it may be that the necessary level of force varies with receivers. And it may be that mean force over multiple trials is not a meaningful measure. We hope to sort out these issues as we collect additional data. Our expectations with respect to number of points of measurable force, force variability and task completion time are so far being confirmed with the data at hand; more variable application of force, less frequent application of force, and longer time to complete the task appear to have a negative impact on pairwise accuracy.

Finally, there is some very slight evidence that sense of co-presence may turn out to be stronger in more accurate pairs, although we are far more comfortable looking for trends in performance over multiple trials with a handful of participants than we are in looking for relationships between overall performance accuracy and subjective, retrospective assessments of the collaborative environment given only the three pairs. We expect to find additional evidence in support of this relationship as we continue to collect data.

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